I. C. 6255 MARCH, 1930

DEPARTMENT OF COMMERCE

UNITED STATES BUREAU OF MINES
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# SILLIMANITE, KYANITE, ANDALUSITE, AND DUMORTIERITE

BY

ALICE V. PETAR

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# SILLIMANITE, KYANITE, ANDALUSITE, AND DUMORTIERITE[1]

By Alice V. Petar[2]

## FOREWORD

Several years ago the United States Bureau of Mines published a short article[3] describing the andalusite group of minerals and calling attention to new uses then being developed. Since the publication of this earlier report new facts concerning their properties have been determined, and their commercial use has progressed steadily. The bureau receives frequent inquiries concerning andalusite, kyanite, and sillimanite, particularly as regards their occurrence and use. This interest has been due in part to the demonstration of their useful properties by their actual employment in industry. In this age of automotive travel, whether by land, sea, or air, spark plugs are of vital importance in transportation. They are largely made from these minerals. The bureau has visualized this important use in a recent motion picture, Along the Firing Line, or the Story of a Spark Plug.

The present report supplements the bureau's earlier report and embodies later information with regard to sources of supply and potential outlets for this group of allied minerals.

## DESCRIPTION AND PROPERTIES

The minerals andalusite, kyanite, and sillimanite differ in physical properties but have the same chemical composition. They are silicates of alumina having the formula $Al_2O_3.SiO_2$. Although all three are employed in industry they are often referred to indiscriminately as "sillimanite." Another mineral that is closely related to this group is dumortierite.

The physical properties of these minerals are as follows:

1 - The Bureau of Mines will welcome reprinting of this paper, provided the following footnote acknowledgment is used: "Reprinted from U. S. Bureau of Mines Information Circular 6255."

2 - Rare metals and nonmetals division, U. S. Bureau of Mines.

3 - Myers, W. M., New Uses of Nonmetallic Minerals. Bureau of Mines Report of Investigations 2587 Bureau of Mines, 1924, 7 pp.



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| Mineral | Crystallization | Color | Luster | Hardness | Cleavage | Specific gravity |
|---|---|---|---|---|---|---|
| Andalusite | Orthorhombic | Gray, greenish, reddish, bluish | Vitreous, dull | 7.0–7.5 or softer, due to exterior alteration | Prismatic | 3.1 to 3.2 |
| Kyanite | Triclinic | Blue, gray, green, brown | Vitreous | 4 to 5 6 to 7 depending on direction | Macro and brachy pinacoidal | 3.5 to 3.7 |
| Sillimanite | Orthorhombic | White, gray, brown, green | do. | 6 to 7 | Macro-pinacoidal | 3.2 to 3.3 |
| Dumortierite | do. | Bright smalt-blue to greenish-blue | do. | 7 | Macro and brachy pinacoidal | 3.3 |

## HISTORY

Prehistoric implements made of compact sillimanite are found in Western Europe and have a certain resemblance to jade implements,[4] but the mineral was named in honor of Benjamin Silliman, the elder, who was born in 1779.

Kyanite was first described by Saussure[5] who noted in 1785 that when heated it lost its transparency and became opaque white, developed a somewhat open structure, and crumbled easily. More than 15 years later Haüy[6] discovered that andalusite also became white on heating. In 1889[7] and 1890[8] Vernadsky, repeating the experiments of Saussure, found that the change in color and texture took place at 1,320 to 1,380° C. After a careful study of kyanite and andalusite, he concluded that, on heating, both minerals were changed to sillimanite and that sillimanite was unaffected by heat.

4 – Encyclopedia Britannica.

5 – Saussure, H. B. de. Voyages dans les Alpes: Neuch., vol. 4, 1796, pp. 84–5.

6 – Hauy, R. J., Traite' de Minéralogie: Vol. 3, 1801, p. 269.

7 – Vernadsky, W., Note sur l'influence de la haute temperature sur le disthuène. Bull. Soc. franc. Min., vol. 12, 1889, pp. 447–56.

8 – Vernadsky, W., Sur la reproduction de la sillimanite: Bull. Soc franc. Min., vol. 13, 1890, p. 257.

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Similar experiments were made by Beekman[9] in 1902, but after a careful check of the results he concluded that kyanite did not alter to sillimanite on heating. Further studies made by Shepherd, Rankin, and Wright[10] seemed to agree with the findings of Vernadsky, although they were not able to identify the resultant product as sillimanite under the microscope. It was not until 1924 that Bowen and Greig[11] [12] proved that sillimanite, as well as kyanite and andalusite was changed upon heating into a compound $3Al_2O_3.2SiO_2$, with the liberation of silica. The compound was named "mullite." The free silica resulting from the decomposition of the natural mineral was said to be cristobalite.

Just prior to the publication of the results of Bowen and Greig the preparation and use of "artificial sillimanite" was studied at the Northwest Experiment Station of the Bureau of Mines, at Seattle, Wash. The preparation of the material has been described by Sims, Wilson, and Fisher[13], and the results of laboratory tests on its use as a refractory have been summarized by Wilson, Sims, and Schroeder[14] as follows:

> "Alumina-silica mixtures were prepared by fusing quartz, china clay, fire clay, and alumina in the electric furnace. When alumina is less than 68 per cent, crystalline sillimanite ($3Al_2O_3.2SiO_2$) with glass is produced. This material is not very resistant to loads at high temperatures because of the early fusion and internal lubricating action of the glass surrounding the crystals. Above 68 per cent alumina, crystalline corundum appears and the glass is practically absent. This latter composition is very resistant to high-temperature loads when an interlocking, recrystallized bond is developed. This material is not affected materially by acid slags, but it cannot resist basic slags. However, the dense structure of a brick of material above 68 per cent $Al_2O_3$ causes less slagging in a laboratory bath test than silica brick. The laboratory made sillimanite-corundum brick withstood higher temperatures than the best silica, magnesia, chrome, fire clay, or zirconia brick even though the cone of fusion of the former is less than that of MgO, $Cr_2O$ or $ZrO_2$. More and better service tests with a large number of brick fired in large kilns is needed to follow up this laboratory work."

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9 - Beekman, E. H. M., Over't gedrag van distheen en sillimaniet op hooge temperaturen: Verslagen Wisen Natuurk. Afd., Kon. Akademie van Wetenschappen Amsterdam, vol. 11, 1902, pp. 295-7.

10 -Shepherd, E. S., Rankin, G. A., and Wright, F. E. The binary systems of alumina with silica, lime and magnesia: Am. Jour. Sci., vol. 28, 1909, pp. 293-333.

11 -Bowen, N. L. and Greig, J. W., The System $Al_2O_3.SiO_2$: Jour. Am. Ceram. Soc., vol. 7, 1924, pp. 238-54.

12 -Bowen, N. L., Greig, J. W., and Zies, E. G., Mullite, a Silicate of Alumina: Jour. Washington Acad. Sci., vol. 14, 1924, pp. 183-91.

13 -Sims, C. E., Wilson, H., and Fisher, H. C., Preparation of Artificial Sillimanite for Refractory Uses: Trans. Am. Electrochem. Soc., vol. 46, 1924, pp. 513-530.

14 -Wilson, H., Sims, C. E., and Schroeder, F. W., Artificial Sillimanite as a Refractory: Jour. Am. Ceram. Soc., vol. 7, Nov., 1924, pp. 842-855.

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## COMMERCIAL DEVELOPMENT

The commercial utilization of this group of aluminum silicate minerals is a recent development. It had its beginnings during the World War in the search for a suitable insulating material for spark plugs. The synthetic porcelain insulators available at that time did not meet the demands placed upon them in war-time service in airplane engines. In the course of tests at the Bureau of Standards[15] some years ago on spark-plug porcelains it was determined that in a good spark-plug porcelain the quartz should be eliminated from the composition and replaced by some other substance. It was known that the artificial sillimanite found in hard-fired porcelains "if not present in the form of large crystals imparts to the material constancy in volume upon heating, lowers the thermal expansion, and increases the refractoriness and the resistance to sudden heating and cooling." It was therefore thought desirable to produce the mineral synthetically and to introduce it in the porcelain composition in place of quartz, and when this was done it was found that "porcelain in which the clay is lower and all the quartz has been replaced by sillimanite, shows both the lowest thermal expansion and the least variation in the value of the coefficient."

Acting upon the findings of the Bureau of Standards the Champion Porcelain Co. tried to use artificial sillimanite in the manufacture of porcelain but found it impractical commercially. However, Dr. J. A. Jeffery, president of the company, believed that the problem could be solved by the use of natural sillimanite. A suitable deposit of andalusite was found in the Inyo Mountains in California, from which supplies have since been drawn.

In January, 1924, the Bureau of Mines undertook an investigation to determine the possibilities of using kyanite for the manufacture of refractories and high-tension electrical insulators. The study continued for more than two years, and although the results were not published by the bureau several papers prepared by members of the staff of the bureau's Ceramic Experiment Station at Columbus, Ohio, have appeared in the technical press. A preliminary report on the preparation of kyanite refractories was issued by H. C. Harrison[16], in which he described tests on bricks made of various mixes. The kyanite concentrate upon which most of the work was done contained about 93 per cent kyanite and 4 per cent quartz, with 3 per cent accessory minerals. In the bricks made it was found that 20 per cent was about the minimum amount of clay that would give the proper bond, and in some cases it was found desirable to add MgO in small amounts to promote a crystalline bond between the dissociated kyanite grains and the bonding material.

In a study of the electrical resistance of various ceramic materials at high temperatures R. M. King[17] found that "of the three minerals, cyanite, sillimanite, and andalusite, which have become noted for the formation of mullite in ceramic bodies, the cyanite sample tested seemed to be the best in electrical resistance, with sillimanite and andalusite next in order."

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15 - Bleininger, A. V. and Riddle, F. H., Special Spark-Plug porcelains: Jour. Am. Ceram. Soc., vol. 2, 1919, pp. 564-575.

16 - Harrison, H. C., Cyanite-Clay refractories: Jour. Am. Ceram. Soc., vol. 9, 1926, pp. 257-278.

17 - King, R. M., The Electrical Resistivity of Some Ceramic Materials at Elevated Temperatures and a Simple Commercial Method for Its Determination: Jour. Am. Ceram. Soc., vol. 9, 1926, pp. 343-350.

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McDowell and Vachuska[18] studied the effect of calcined kyanite in porcelain bodies and reported that:

> "Mullite introduced as calcined cyanite, ground to a proper fineness and introduced in feldspar, flint clay porcelain bodies in amounts over 30 per cent has the following tendenices on the physical properties of the bodies:
>
> "1. Increase in modulus of rupture.
> 2. Decrease in coefficient of expansion.
> 3. Increase in firing temperature required.
> 4. Increase in firing range.
> 5. Color gradation from white to gray due to the iron bearing accessory minerals.
>
> "Thirty per cent or more of the material is required to produce marked changes in the body due to the fact that there is little or no seeding effect, i.e., secondary mullite growth, from the cyanite grains. These apparently act merely as inert particles with desirable physical properties."

Harrison's work was supplemented by Vachuska and Bole[19], who found that the addition of 20 per cent or more kyanite tends to counteract the shrinkage of diaspore during continued use at high temperatures.

## USES

The use of andalusite minerals in the manufacture of spark plugs has already been mentioned. This was the first use and is still by far the best known. The Champion Spark Plug Co. and its subsidiary, the Champion Porcelain Co., which were responsible for the development of "sillimanite" spark plugs, later engaged in the production of laboratory ware, including crucibles, casseroles, evaporating dishes, and other heat-resisting articles. Owning its own deposits in California and Nevada this concern has ample supplies of raw material. In its catalog the claim is made that much less "sillimanite" ware than chemical porcelain is broken under the same conditions of use.

The use of mullite refractories in the glass industry has been described by W. A. Koehler[20] as follows:

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18 - McDowell, Samuel J., and Vachuska, Edward J., The Effect of Calcined Cyanite in Porcelain Bodies: Jour. Am. Ceram. Soc., vol. 10, 1927, pp. 64-72.

19 - Vachuska, E. J. and Bole, G. A., Notes on Cyanite and Diaspore Refractories: Jour. Am. Ceram. Soc., vol. 10, 1927, pp. 761-73.

20 - Koehler, W. A., Mullite Refractories Extend Field of High-Temperature Processes: Chem. and Met. Eng., vol. 35, Feb., 1928, pp. 86-88.

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"The big field for mullite refractories at present is in the glass industry. With the introduction of glass blowing machinery, glass tanks are operated at higher temperatures and at faster rates, so that the industry has been facing the problem of decreasing tank block life. Glass house refractories that come in contact with the molten glass have generally been limited to fire-clay, or in special cases to porcelain, but mullite appears as a very promising material. In a glass tank under heavy duty the tank must be relined every ten to fifteen months, while under similar conditions mullite blocks have served three years and are still in service. For best service, the lower part of the tank, to just above the flux line, should be made of recrystallized or cast mullite blocks, but the superstructure, although also of mullite, may be built of molded blocks.

"Besides glass tank blocks, other fields for mullite refractories are glass pots, enamel furnaces, electric furnaces, muffles, piers, checkers in water gas carbureters and any parts of furnaces subjected to high temperatures, especially where high rigidity and non-shrinking and spalling characteristics are very desirable."

## Uses of Kyanite

Recent tests indicate that in firing electrical porcelain saggers containing kyanite have a much longer life than those made from ordinary mixtures. Kyanite has likewise been used, more or less experimentally, in spark plugs, for refractory brick, in electrical porcelain and chinaware, and in glass and enamelware.

The Vitrefrax Co. of Los Angeles produces kyanite from a very large deposit in Imperial County, Calif., for use in the manufacture of various ceramic materials for the porcelain, white ware, and electrical insulator trade and including superrefractories in the form of prepared grains, cements, and finished raw materials, together with a line of refractory brick and shapes for the glass industry. The products manufactured by the company have been described as follows:[21]

"The mullite products of the company constitute its most important line. The material is manufactured in several grades, one of which is made especially for the spark-plug industry. * * *

"The most important application of the mullite refractory material in its highest state of purity is in the form of glass-house refractories, in which the company's product is gaining important recognition. Excellent service is being obtained in many commercial in-

21 - Dietrich, Waldemar Fenn, The Clay Resources and the Ceramic Industry of California: California State Min. Bur. Bull. 99, 1928, pp. 121-2.

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stallations on the Pacific coast, while an awakening interest in the east has caused orders to be placed by a number of prominent glass manufacturers within the past year.

"For the general refractories trade, for use in heavy-duty boiler refractories and the like, a cheaper grade of mullite is manufactured and sold under the trade mark 'California Mullite.'"

## Uses of Dumortierite

Dumortiertie is used with andalusite in the manufacture of porcelain for spark plugs. The only commercial deposit now known is in Pershing County, Nev., and is owned and operated by the Champion Porcelain Co. of Detroit. The special qualifications of dumortierite for refractory use have been described as follows:[22]

"The mineral forms a good basis for refractory material because of its high alumina content. It has important advantages over sillimanite, andalusite, and cyanite. Dumortierite burns to a practically pure white product. Dr. J. A. Jeffery informed the writer that it increases the toughness and electrical resistivity of porcelain and allows a greater temperature range in burning than does andalusite. It has a high fusion point, and porcelain made from a mixture of dumortierite and andalusite has a very low coefficient of expansion. Experimental ware made by the Champion Porcelain Company indicates that if sufficient dumortierite can be obtained its applications would multiply many fold. Greatly improved pyrometer tubes, chemical porcelain ware, and dishes have been made of it. The pyrometer tubes do not become porous or brittle after over a year's use in a kiln. The porcelain ware resists both mechanical shock and sudden changes in temperature much better than does the porcelain now in general use. By using the proper mixture of andalusite and dumortierite a high grade refractory brick has been made by the Champion Company for use in their own kilns. Bricks made of dumortierite alone gradually swell and those made of only andalusite sag so that a proper mixture of the two yields a brick of just the right quality. The present known occurrence of commercial dumortierite is too limited to permit its employment in any field other than in the manufacture of spark plug porcelain."

## MANUFACTURE OF MULLITE REFRACTORIES

Mullite refractories may be made by fusing alumina and silica in an electric furnace, but at present they are made principally from the natural aluminum silicates.

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22 - Palmer, Walter S., Ore Dressing Tests: Bull. Univ. of Nevada, Dumortierite, vol. 22, No. 2, March 15, 1928, p.41



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The three minerals kyanite, andalusite, and sillimanite are converted by heat to mullite and silica or to mullite and a siliceous liquid, but they are not interchangeable. The lowest temperature at which the alteration takes place is different for each mineral. Kyanite alters at the lowest temperature, sillimanite at the highest. In none, however, does the change take place sharply at any definite temperature, but progresses slowly over a considerable range. The progress of this change is described by Greig[23] as follows:

> "In the cases of cyanite and of andalusite the alteration commences on the surfaces of the grains and advances inward. In that of sillimanite the change seems to take place throughout the grain.
>
> "In all three minerals the rate of decomposition increases rapidly with rise of temperature.
>
> "When andalusite and sillimanite are decomposed, the newly formed mullite crystals are oriented parallel to the original crystals: with cyanite this orientation is determined by the surfaces from which the mullite grows.
>
> "The decomposition of cyanite and of andalusite is shown to be accompanied by an absorption of heat.
>
> "In all three cases the new phases formed are of lower density than the original mineral, so there is an expansion accompanying the decomposition."

Dumortierite can be converted to mullite below 1250° C., and hence it too can be incorporated into white ware without precalcination.[24]

Mullite refractories may be manufactured either in the electric furnace or in gas or oil fired kilns.

## MINING AND PREPARATION

In California and Nevada, where andalusite and dumortierite respectively are produced by the Champion Porcelain Co., the material is mined selectively and hand sorted. Both properties being situated some distance from a railroad, the selection of material is made carefully. At the California property, the sillimanite rock must be transported in sacks by burros down a steep trail 4½ miles long to the valley 6,000 feet below, where it is placed upon motor trucks and hauled 3 miles farther to the railway siding at Shealy, Calif., and then by rail to Detroit. At the mine the large rocks are broken by hand into

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23 - Greig, J. W., Formation of Mullite from Cyanite, Andalusite and Sillimanite: Jour. Am. Ceram. Soc., vol. 8, Aug. 1925, p. 483.

24 - Koehler, W. A., Mullite Refractories Extend Field of High-Temperature Processes: Chem. and Met. Eng., vol. 35, Feb. 1928, p. 88.

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small pieces and placed in sacks at once, the sacks protecting the mineral from contamination during storage. The selection of the material is based upon frequent specific gravity tests made by means of a Jolly balance. At the railroad the sacks are dumped into carefully cleaned box cars.

Upon arrival at Detroit[25] the material as it is unloaded from each car is spread or bedded horizontally in long parallel strips. Forty-five carloads form one large pile containing 2,000 tons. Three such piles are maintained; one pile serves as the source of the raw material while the next pile is being formed, and one is kept always in reserve. To get a uniform mixture the material is withdrawn from a pile along a face at right angles to the parallel strips or beds in which it was deposited, and a complete cut across the pile is made at each withdrawal, thus containing a segment of each carload.

The andalusite is first crushed in jaw crushers to less than 1 inch in diameter and is then stored in elevated bins from which it travels by gravity chutes into Hardinge mills where it is ground by steel balls to 7 mesh or finer. After passing over magnetic separators to remove particles of iron from the ball mill the ground material passes to a second conical mill lined with "sillimanite" and containing pebbles of "sillimanite," in which it is ground to 100 mesh and finer. The resultant fine powder is transferred by screw conveyors to large hoppers holding approximately 1 ton, and these hoppers dump into storage bins.

The dumortierite from Nevada is also shipped to the Champion plant at Detroit and is treated in similar fashion to the andalusite. Describing the preparation of the "sillimanite" for use in spark-plugs Walter S. Palmer[26] says:

> "In preparing the body the ground dumortierite is mixed with ground andalusite, kaolin, and water and the grinding continued in a special mill having a capacity of about 2 tons. Here the grinding is done in batches, and a charge will be ground for about 17 hours. The slip or ground body will then pass a 300-mesh screen. The material then passes to filter presses where the excess water is removed. The cakes from the presses are stored in an aging cellar for 10 days. This aging develops plasticity and gives time for each batch of material to be tested.
>
> "From the aging cellars the material passes through two pugging mills before being formed into the blanks from which the spark plugs are made. After thorough drying the blanks are turned down on special lathes and given their final form. The tolerance allowed is one three-thousandth of an inch. The cores are then glazed and are ready for burning.

25 - Riddle, Frank H. and Royal, Herbert F., Process Control in Continuous Production - System of the Champion Porcelain Co.: Ind. and Eng. Chem., vol. 22, Jan., 1930, p. 15.

26 - Palmer, Walter S., Ore-Dressing Tests: Bull. Univ. of Nevada, Dumortierite, vol. 22, Mar. 15, 1928, p. 42.

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"The cores are burned in a continuous kiln 300 feet long, at a temperature of 3700°F. It takes four days for the cores to pass through the kiln."

The treatment of "sillimanite" for laboratory ware has been described in The Story of Sillimanite Laboratory Ware,[27].

"The material from the aging cellar which is to be made into laboratory shapes is mixed with the proper amount of water in large mixing vats known as 'blungers.' This converts it again into slip. The slip which is of about the consistency of thick cream, is then poured into molds made of plaster of Paris, the hollow centers having the exact shape of the desired piece of laboratory ware, such as a crucible or evaporating dish. The plaster rapidly absorbs the water and the plastic material is deposited in an even, uniform, homogeneous layer over the surface of the mold. This process is known as 'casting.' The excess slip is poured out and after a few minutes, during which the material becomes stiffer, due to the removal of the excess water by absorption into the dry plaster, the mold is mounted on a vertical lathe or turn table, and by means of a properly shaped turning tool, the material is 'jiggered' (turned or spun) to the proper shape and wall thickness.

"Upon further drying, the plastic material shrinks sufficiently so that the article can be easily removed from the mold. The edges are smoothed by hand, each piece is carefully inspected for defects and the thickness tested by peiodic weighings. The 'green' ware is dried for a certain period, then placed in 'saggers', which are stacked upon the cars in vertical 'bungs' or columns prior to being pushed into the kiln. * * * * *

"In the plant of the Champion Porcelain Co. of Detroit all sillimanite ware is fired in a Dressler tunnel kiln in which physical and chemical conditions are controlled and held uniform for a year at a time without the kiln ever being cooled down."

Of the mullite products manufactured by the Vitrefrax Co. of Los Angeles the highest grade, "durox," is made by fusing a specially concentrated kyanite in the electric furnace at a temperature of about 3,000° C. A cheaper grade of mullite is also manufactured by the company and sold under the name "California mullite."

In North Carolina kyanite occurs massive and disseminated through schists. Since the specific gravity of kyanite is roughly 3.6 or about the same as garnet, tests have

27 - Central Scientific Co The Story of Sillimanite Laboratory Ware: 1928, p. 10.

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indicated that it can be freed completely from the accompanying gangue by crushing to 28 mesh and in certain cases to much coarser sizes, which could be treated economically by means of jigs and tables.

Tests made at the Bureau of Mines experiment station at Rolla, Mo., about 1926 demonstrated the possibility of producing a concentrate containing under 2 per cent of free quartz and the elimination also of most of the heavier gangue.

## PRODUCTION

In the United States the commercial production of these aluminum silicate minerals apparently commenced in 1920 and has progressed more or less steadily since that year. Practically no statistics are available, however, for production in this country.

In California from 1922 to 1926, inclusive, the total production of the sillimanite group of minerals amounted to 9,394 tons, valued at $301,790.

In Nevada figures of production are not available, since there is only one producer. The Champion Porcelain Co., however, has operated its dumortierite property fairly steadily since commencing operations in the latter part of 1925.

In Virginia the McLanahan-Watkins Co. at Charlotte Court House has operated intermittently.

In North Carolina a few tons have been mined from time to time, chiefly for experimental purposes.

Considerable experimental work directed toward the utilization of kyanite has been done in Germany in recent years, as for example by Heinrich Koppers at Essen, but outside of the United States the only production — at least on an extensive scale, — appears to have come from British India. In 1928, 2,241 tons of kyanite valued at £2,509 was produced in the Singhbhum district, as compared with 4,425 tons valued at £1,866 in 1927. The greater part of this production came from the Lapso Hill mines in Kharsawan State — 1,896 tons in 1928 and 3,665 tons in 1927. A smaller quantity, 345 tons, was produced from E. O. Murray's mines at Ghagidih. The principal producer of kyanite in India is said to be the Indian Copper Corporation from the Lapsa Buru mine. The material is marketed in England by the P. B. Sillimanite Co., Ltd.[28]

A certain amount of sillimanite shipped from India was reported in the statistics as corundum, with which it is associated, and it was not until 1921 that material from the Khasi Hills was known to contain sillimanite. Complaints from purchasers in London because of the lack of hardness of a consignment led to a chemical and microscopical examination,

28 - Mining Journal (London), The Aluminous Refractory Materials; Kyanite, Sillimanite and Corundum in Northern India: Vol. 167, Nov. 2, 1929, p. 876.

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which revealed in one of the brands over 35 per cent of silica and a hardness of about 6.5 instead of 9. At the same time, however, it was pointed out that as a refractory, especially for glass furnace use, sillimanite was of greater value than corundum. The Khasia Mines Ltd. went into liquidation in 1922 and stocks of the sillimanite-corundum rock on hand in London have been disposed of. A few years later H. A. Golwynne of New York City purchased a sillimanite property in India which has been subsequently operated, and it is reported that sillimanite brick has been produced from this Indian material and offered on the American market at $1 per brick.

## OCCURRENCES

### Occurrence of sillimanite

#### United States

In the United States many scattered occurrences of sillimanite have been reported, but no production of consequence has been made. The products of the Champion Porcelain Co. are marketed under the trade name "sillimanite," but the principal ingredients are andalusite and dumortierite.

## FOREIGN

The largest known deposits of natural sillimanite are in India, in Assam, in the neighborhood of Sona Pahar, north of the village of Nongmaweit, in Nongstoin State, and in Rewa State, Central India, near Pipra. At the former deposit, which is on the Khasi Hills Plateau, it has been estimated[29] that there is a total quantity of 83,000 tons available, including float ore. The deposits consist mainly of massive sillimanite, with a little corundum. The deposits in Assam are very inaccessible, being reached by motor truck from Gauhati 36 miles west to Boko, by bullock cart 12 miles south to Haima at the foot of the Khasi Hills, and finally a march south into the hills for 23 miles. It is stated that a branch line from the proposed new railway along the south bank of the Brahmaputra River has recently been contemplated, which would make the deposits more accessible.

The deposit in Rewa is estimated to contain 1,000,000 tons of poor material and 100,000 tons of higher grade sillimanite. The deposit is associated with sillimanite schists and pyroxene-bearing rocks, and separation of high grade sillimanite is difficult. Here too, transportation is a handicap, as the material must be carried about 120 miles by bullock pack to Mirzapur for rail shipment to Calcutta.

A smaller occurrence of corundum and sillimanite has been noted in the Bhandara district of the Central Provinces, but it does not appear to be important.

### Occurrence of Andalusite

#### United States

California

The largest known deposit of andalusite is that of the Champion Porcelain Co.,

29 - Pascoe, Edwin, Records of the Geological Survey of India: Vol. 61, pt. 1, 1928, pp. 68-71.

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in the White Mountains of the Inyo Range, in Mono County. It is located at an elevation of 10,000 feet on the southwestern slope of White Mountain and is said to contain very large reserves.

South Dakota

Occurrences of andalusite have also been noted in South Dakota, where it is found in the central Black Hills in a belt of pegmatitic masses extending from near Oreville northeastward to Summit Peak. During 1925 trial lots amounting to about sixteen tons, valued at $635, were shipped by three producers — the Black Hills Mining Co. and George B. Grant of Custer and Mills Bros. of Hill City. While the material was suitable for the manufacture of spark plugs the prospects do not appear to be large enough to insure large-scale production.[30]

### Foreign Countries

Deposits of andalusite have been reported in Nova Scotia, but so far as known they have not been worked commercially. The mineral has also been found in large white lumps showing crystal faces at Chenderdang, British Malaya, and with pinkish mica and quartz as a vein in limestone at Gopeng. The variety known as chiastolite has been found in small quantity in several localities.

## Occurrence of Kyanite

### United States

Kyanite occurs in varying quantities in Arizona, California, Georgia, Massachusetts New Mexico, North Carolina, Pennsylvania, Virginia, and Wyoming. The largest production has been from California, but substantial quantities appear to be available in North Carolina Virginia, and other States.

Arizona

Kyanite is said to occur north of Yuma in stout crystals associated with dumortierite.

California

An extensive deposit of kyanite occurs near Ogilby and is operated by the Vitrefrax Co. of Los Angeles. The deposit has been described by the California State Mining Bureau[31] as follows:

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30 - Lincoln, F. J., Rock Products Industry of South Dakota: Rock Products, vol. 30, April 30, 1927, pp. 53-56.

31 - Dietrich, Waldemar Fenn, The Clay Resources and the Ceramic Industry of California: California State Min. Bur. bull. 99, 1928, p. 87.

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"The deposits of cyanite occur near the base of hills on the western slope of the Cargo Muchacho range of mountains, three miles northeast of Ogilby. Elevation 500 feet. Holdings comprise ten claims known as the Drifted Snow and Blue Bird groups. 200 acres. Owner, Vitrefrax Company, 5100 Pacific Boulevard, Los Angeles.

"The first discovery of cyanite was made in a low, rounded hill one-eighth mile wide by one-half mile long, and probably consists of 25 per cent cyanite in a matrix of quartz. One-quarter of a mile farther east, a prominent vein of cyanite outcrops for one-half mile in length, at the foot of the Cargo Muchacho range. The vein, which occurs in a mica schist, is nearly vertical and varies from 10 to 200 feet in width. Open cuts and tunnels have been made along the deposit for a distance of over 500 feet along the strike. The most extensive showing has been found on the north end of the deposit. Here it outcrops for over 200 feet in width. Quartz is the gangue mineral, while small amounts of black tourmaline occur throughout the vein material. On the south end of the deposit, both walls of the vein have a selvage of talc.

"Eight to ten men are employed in getting out material for shipment to the company's plant at Los Angeles, where it is being used in the manufacture of high-grade refractories."

Georgia

Occurrences of kyanite are reported from Ball Ground, Cherokee County and from Cobb, Habersham, and Upson Counties. There has been some reported activity in Habersham County, but so far as the bureau knows no production of consequence has been made.

Massachusetts

Specimens have been found at Chesterfield, Hampshire County.

New Mexico

A number of specimens of kyanite-bearing schist have been sent to the United States Bureau of Mines from Rio Arriba and Taos Counties.

North Carolina

Extensive deposits of kyanite are reported in North Carolina, principally in Yancey County, where it occurs in large quantities in a schist on the north end of the Black Mountain Range.[32] In this particular locality it makes up 10 to 40 per cent of the rock

32 - Bryson, Herman J., The Mining Industry in North Carolina during 1926: North Carolina. Dept. of Conservation and Development, Econ. Paper 62, 1928, p. 35.

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mass, the accessory minerals being chiefly quartz, mica, and garnet with smaller amounts of tourmaline, staurolite, and corundum. At one property a process is said to have been perfected which gives a concentrate carrying 98 per cent of kyanite. Other occurrences in Yancey County noted by Bryson are south of Micaville, on Cattail Mountain, and near Black Mountain. At the latter locality the kyanite has a massive structure, showing little schistosity. Other occurrences are in Clay, Iredell, Haywood, Cherokee, Graham, Caldwell, Jackson, Mitchell, Avery, and Wilkes Counties.

Pennsylvania

Specimens have been obtained at Darby, in Delaware County.

Virginia

A deposit of kyanite near Charlotte Court House has been worked for several years by the McLanahan-Watkins Co., which has operated a concentration plant. The kyanite is at least in part, in a quartzite and is said to be in large quantity. The kyanite is accompanied by more or less rutile.

Wyoming

Deposits, said to be of commercial importance, have been reported from the vicinity of Wheatland.

## Foreign Countries

There are a number of kyanite deposits in the eastern part of India, in Bihar and Orissa. The largest of these are in the province of Singhbhum, and have been described by Sir Edwin Pascoe[33] as follows:

> "Here a series of deposits of kyanite rock extends over 70 miles in the Singhbhum district, Bihar and Orissa, through the native states of Kharsawan and Seraikela, and the Dhalbhum subdivision. The main rock is a muscovite-schist, but hornblende-schist is very frequently met with. The mica-schist often contains large crystals of staurolite and garnet. Dr. Dunn observes that the rock with which the massive kyanite is usually associated is a kyanite-quartz-rock, or granulite. At Lapsa Buru this rock is found in enormous beds, the massive kyanite occurring as segregations in the more acid rock. * * *
>
> "The largest deposit is that at Lapsa Buru at the western end of the belt. Here the debris alone would probably provide a minimum of 234,000 tons of kyanite-rock. The actual quantity may be ten times this amount. Another good deposit is at Ghagidih, about 3 miles south of Jamshedpur, where over 20,000 tons are available.

33 - Pascoe, Edwin, Records of the Geological Survey of India: Vol. 61, pt. 1, 1928, pp. 68-71.

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"At Rahka Mines there are perhaps several hundred tons of massive kyanite in the alluvium shed from the kyanite-quartz-rock. In the remainder of the belt to the southeast of Rakha Mines there is little or no massive kyanite-rock associated with the kyanite-quartz granulite, but the latter may find a market in the future."

## Occurrence of Dumortierite

### United States

Dumortierite has been reported in Arizona, California, Colorado, Nevada, New Mexico, New York, and Washington, but the only deposit of commercial importance appears to be in Nevada. There are four occurrences of dumortierite in Nevada. The largest of these, in Humboldt Queen Canyon, 6 miles east of Oreana, Pershing County, was purchased by the Champion Porcelain Co. of Detroit, Mich., in October, 1925. As previously noted, this company employs dumortierite mixed with andalusite in the manufacture of spark plug porcelain.

Dumortierite has been reported from many parts of the world, notably France, German Silesia, Switzerland, Czechoslovakia, Russian Urals, southern Norway, Scotland, Cornwall, England, Madagascar, Argentina, Brazil, Canada, and Mexico. In each place the mineral seems to be in comparatively small quantity.

## IMPORTS AND EXPORTS

Indian sillimanite has been on the American market since about 1923 and is said to be of good quality. Imports of sillimanite, however, are not listed separately, and no reliable estimates are available as to the quantity received from India or other countries. Small shipments of American kyanite appear to have been made from time to time to Europe, but chiefly for experimental purposes, and no regular trade has yet developed.

## MARKETS AND PRICES

The demand for the four minerals has not been extensive. The largest consumers have their own deposits which have apparently been of sufficient size to satisfy their needs. However, there is reason to believe that a producer who could guarantee an assured tonnage of kyanite, reasonably free from mica, garnet and similarly undesirable impurities, would be able to secure orders promptly for 10,000 to 15,000 tons and perhaps considerably more annually. Since much of this business would have to be taken in competition with other refractory raw materials, the price would doubtless be determined on the basis of actual performance. The foregoing estimated tonnage is based on an assumed price of $15 to $20 delivered at Pennsylvania plants.

The price of sillimanite in England has recently been reduced from £14 to £11 per ton. Indian kyanite is marketed by the Indian Copper Corporation at Rs. 36 per ton f.o.r. Amda, Bengal-Nagpur Railway line.

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The Bureau of Mines attempts to keep in touch with producers and buyers of the various minerals and metals, so that it may help producers in finding a market for their material or may aid buyers and users in locating sources of supply of the ores in which they are interested. The names of the following persons and firms have come to the attention of the bureau as being interested in the group of minerals covered in this report. Although the list is by no means complete, it is hoped that it may prove helpful to persons engaged in the industry.

Possible producers and dealers

H. M. Calhoun, Elkin, N. C.
J. H. Tate, Marion, N. C.
J. A. Pollard, Burnsville, N. C.
Col. D. W. Adams, Old Fort, N. C.
A. F. Holcomb, Hamptonville, N. C.
Joel T. Watkins, Charlotte C. H., Va.
J. D. Roberts, Ball Ground, Ga.
Wm. J. Hanley, Ogilby, Calif.
Vitrefrax Co., Los Angeles, Calif.
J. Frank Beck, Atlanta, Ga.
Parco Development Co., Parco, Wyo.
Charlotte Chemical Laboratories, Charlotte, N. C.
Mineral Products Sales Corp., 135 Front St., New York City.
Varlacoid Chem. Co., 15 Moore St., New York City.
Champion Porcelain Co., Detroit, Mich.
George B. Grant, Custer, S. Dak.
Pettit & Coates, Hill City, S. Dak.

Possible buyers

H. C. Bugbird Co., 58 Pearl St., New York City.
Exolon Co., Commercial Ave. & Erie R. R., Blasdell, N. Y.
A. D. Mackay, 26 Cortlandt St., New York City.
National Sales Corp., 31-35 E. 13th St., Cincinnati, Ohio.
The Findlay Clay Products Co., Washington, Pa.
A. C. Spark Plug Co., Flint, Mich.
Harbison-Walker Refractories Co., Pittsburgh, Pa.
Corning Glass Co., Corning, N. Y.
U. S. Refractories Corp., Mt. Union, Pa.
General Refractories Co., 117 S. 16th St., Philadelphia, Pa.
E. J. Lavino, Bullitt Bldg., Philadelphia, Pa.

BIBLIOGRAPHY

Andalusite

Greig, J. W. Formation of mullite from cyanite, andalusite and sillimanite. Jour. Am. Ceram. Soc., vol. 8, Aug., 1925, pp. 465-484.

Digitized by Google

Melhase, J. Andalusite in California. Eng. and Min. Jour., vol. 120, July 18, 1925, pp. 91-94.

Peck, Albert B. Note on andalusite from California: A new use and some thermal properties. Am. Mineral., vol. 9, June 1924, pp. 123-129.

Kyanite

Dietrich, Waldemar Fenn. The clay resources and the ceramic industry of California. California State Min. Bur., Bull. 99, 1928.

Fessler, A. H. and McCaughey, Wm. J. Cyanite as found in Western North Carolina. Jour. Am. Ceramic Soc., vol. 12, Jan., 1929, pp. 32-36.

Greig, J. W. Formation of mullite from cyanite, andalusite and sillimanite. Jour. Am. Ceram. Soc., vol. 8, Aug., 1925, pp. 465-484.

Harrison, H. C. Cyanite-clay refractories. Jour. Am. Ceram. Soc., vol. 9, 1926, pp. 257-278.

McDowell, Samuel J. and Vachuska, Edward J. The effect of calcined cyanite in porcelain bodies. Jour. Am. Ceram. Soc., vol. 10, 1927, pp. 64-72.

Vachuska, E. J. and Bole, G. A. Notes on cyanite and diaspore refractories. Jour. Am. Ceram. Soc., vol. 10, 1927, pp. 761-73.

Sillimanite

Bowen, N. L. and Greig, J. W. The System: $Al_2O_3.SiO_2$ Jour. Am. Ceram. Soc., vol. 7, 1924, pp. 238-54.

Canadian Min. Jour. Sillimanite in India. Vol. 49, Oct. 19, 1928, p. 859.

Cousen, A. and Turner, W. E. S. Some uses of commercial sillimanite in glass works. Jour. Soc. Glass Tech., vol. 10, 1926, pp. 416-24. Ceram. Abs., vol. 6, 1927, pp. 223-4.

Greig, J. W. Formation of mullite from cyanite, andalusite and sillimanite. Jour. Am. Ceram. Soc., vol. 8, Aug., 1925, pp. 465-484.

Rees, W. J. Some notes on the use of Indian sillimanite. Quarry and Surv. and Contract. Jour. vol. 32, No. 366, London, 1927, pp. 287-289.

Sims, C. E., Wilson, H., and Fisher, H. C. Preparation of artificial sillimanite for refractory uses. Trans. Am. Electrochem. Soc., vol. 46, 1924, pp. 513-530.

Turner, W. E. S. Natural sillimanite as a refractory material in the glass industry. Glastech. Ber., vol. 5, 1927, pp. 4-12. Ceram. Abs., vol. 6, 1927, pp. 447-8.

Digitized by Google

Wilson, H., Sims, C. E., and Schroeder, F. W. Artificial sillimanite as a refractory. Jour. Am. Ceram. Soc., vol. 7, Nov. 1924, pp. 842-855.

Dumortierite

University of Nevada Bulletin. Dumortierite. Vol. 22, No. 2, March 15, 1928.

Schaller, W. T. Dumortierite. Am. Jour. Sci., ser. 4, vol. 19, 1905, pp. 211-224.

Schaller, W. T. Dumortierite. U. S. Geol. Survey Bull. 262, 1905, pp. 91-120.

Peck, A. B. Dumortierite as a commercial mineral. Am. Mineral., vol. 11, 1926, pp. 96-101.

Wilson, Eldred D. An occurrence of dumortierite near Quartzite, Arizona. Am. Mineral., vol. 14, Oct., 1929, pp. 373-381.

General

Bole, G. A. Some new refractories now in process of development. Eng. and Min. Jour., vol. 125, 1928, p. 682.

Koehler, W. A. Mullite refractories extend field of high temperature processes. Chem. and Met. Eng., vol. 35, Feb., 1928, pp. 86-88.

Lilley, D. D. Should glass tank blocks be mullite or flux block? Ceram. Ind., vol. 8, 1927, pp. 166-70.

Myers, W. M. New uses of nonmetallic minerals. Bureau of Mines Serial 2587, March, 1924, pp. 1-4.

Brick and Clay Record. About mullite brick. vol. 70, 1927, p. 114.

Sprechsaal. Mullite tank block. Vol. 60, 1927, p. 284. Ceram. Abs., vol. 6, 1927, p. 589.

Mining Journal (London). The aluminous refractory materials: Kyanite, sillimanite and corundum in Northern India. Vol. 167, Nov. 2, 1929, p. 876.

Riddle, Frank H. and Royal, Herbert F. Process control in continuous production - System of the Champion Porcelain Co. Ind. and Eng. Chem., vol. 22, January 1930, pp. 14-20.

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